Smart IoT-Based Maritime Boundary Alert System for Fishermen

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Abstract—The integration of Internet of Things (IoT) technology and real-time GPS tracking in the maritime sector delivers a robust and automated solution to the longstanding problem of accidental border crossings by coastal fishermen. Despite advancements in navigation tools, many traditional fishermen still rely on basic equipment and lack precise awareness of maritime boundaries, exposing them to legal consequences such as arrest, detention, or fines when entering foreign waters. This paper presents a smart, low-cost Fisherman Border Alert System built on the ESP32 microcontroller, which operates with a GPS module, multi-color LED indicators, a buzzer, and an SOS emergency button. The system monitors the vessel's real-time coordinates and compares them to predefined geofencing boundaries that represent national maritime limits. It features a three-stage alerting mechanism—soft initial warnings, critical alerts when nearing boundaries, and an SOS stage enabling manual distress signaling. The solution functions in both offline and online modes, with optional integration to Firebase or cloud platforms when internet access is available, enabling remote monitoring. Power-efficient and solar-compatible, this device is designed to operate under marine conditions with minimal human intervention. It automates the entire process of boundary detection and alerting, enhances safety, reduces the risk of international violations, and enables fishermen to focus on their livelihood with greater confidence, peace of mind, and legal security.

Keywords — fishermen safety, maritime boundary, GPS, ESP32, IoT, geofencing, SOS alert, border monitoring, real-time tracking, automation

I. Introduction

Fishing is one of the oldest, most vital, and economically significant activities for coastal populations across the globe. In countries like India, Sri Lanka, Bangladesh, and other coastal nations, a large percentage of rural and semi-urban populations rely on fishing as their primary livelihood. Despite its importance, traditional fishing still relies heavily on manual techniques and local navigation knowledge, passed down through generations without access to modern maritime safety systems.

One of the major risks faced by these fishermen, particularly those operating close to international maritime boundaries, is the accidental crossing of borders into foreign territorial waters. Due to the vastness of the sea and the absence of physical demarcations in water, fishermen often do not realize when they cross into the jurisdiction of another country. These unintended intrusions frequently result in serious consequences such as detainment, heavy penalties, confiscation of boats, or even imprisonment by foreign coast guards.

These incidents are not only tragic from a human rights perspective but also have wider diplomatic implications. Maritime boundary violations, even if accidental, strain international relations and often involve complex legal and political interventions to resolve. The families of affected fishermen suffer both emotionally and financially, and the recurring nature of such events indicates a systemic problem. While technological advances in the marine sector have provided commercial and defense vessels with sophisticated tools such as radar systems, satellite communications, and digital navigation maps, such solutions remain financially and logistically out of reach for small-scale, traditional fishermen. Most of them operate on modest earnings, using wooden or fiber boats without any onboard technology. What they need is not a high-end, complex solution but a simple, cost-effective, and reliable system that can warn them when they are approaching danger zones and allow them to act before it's too late. Recognizing this urgent need, this project aims to develop a Smart IoT-Based Fisherman Border Alert System that is affordable, efficient, and robust enough to be deployed on traditional fishing boats. The system leverages the capabilities of modern IoT hardware, primarily the ESP32 microcontroller, in conjunction with a GPS module, buzzer, multicolor LED indicators, and an SOS emergency push button. The goal is to create an automated system that continuously monitors the boat’s position using GPS coordinates and compares it to predefined geofenced maritime boundaries programmed into the device. Based on the boat’s proximity to the boundary, the system activates one of three alert stages: a soft early warning with a yellow LED and low buzzer sound when nearing the boundary, a critical alert using a flashing red LED and louder buzzer if the boat gets too close or crosses the border, and finally, an emergency mode triggered by the fisherman via the SOS button in extreme cases.

One of the distinguishing features of this system is its ability to work in both online and offline environments. While the system can send real-time location data to cloud platforms such as Firebase for centralized monitoring when internet connectivity is available, it is also designed to function independently of the cloud. This is crucial for sea operations, as cellular networks are often weak or nonexistent farther offshore. The system is designed to be powered by a rechargeable battery or a solar panel, ensuring that it remains operational for extended durations without depending on external power sources. The entire setup is enclosed in a waterproof casing to withstand marine weather conditions, making it rugged enough for daily use by fishermen.

II. RELATED WORK

The problem of unintentional maritime border crossing by fishermen has been widely acknowledged and several researchers have proposed technological interventions leveraging IoT and GPS technologies. However, most existing systems either lack offline capabilities, multistage alert mechanisms, or are too complex or costly for small-scale fishermen to use effectively.

P. Arun Mozhi Devan and R. Ramesh [1] proposed a GPS and GSM-based system for tracking fishing boats and alerting fishermen via SMS when approaching maritime boundaries. The system employed a microcontroller to compare the real-time GPS coordinates with predefined boundary data and used a GSM module to send alerts to the fishermen's mobile phones. While this approach was effective in regions with strong mobile network connectivity, the reliance on SMS as the primary communication method posed limitations for fishermen operating in deep-sea areas where mobile signal is weak or absent. Furthermore, the system lacked visual or audible alert indicators, which are essential for immediate awareness in real-time.R. Ramya and T. Vignesh [2] introduced a border alert system using ZigBee wireless communication modules along with GPS technology to transmit data to monitoring stations. This approach facilitated real-time monitoring of the boat’s location but suffered from a limited range due to ZigBee’s short-range communication capabilities. As a result, this system was more suitable for inland waters or nearshore activities and could not scale to deep-sea applications. Moreover, the system was heavily reliant on ground-based monitoring infrastructure and did not empower the fishermen with local alerts or autonomous decision-making tools.

K. Ganesh and Dr. T. Sree Renga Raja [3] developed an embedded marine safety system for fishermen that included GPS-based location tracking and obstacle detection using ultrasonic sensors. Their work highlighted the value of combining multiple safety technologies in one system. However, their focus was primarily on physical navigation safety rather than legal or territorial boundary awareness. The system did not implement geofencing or international maritime border alerts, which is the core problem addressed in our proposed work.

T. Mahalakshmi et al. [4] explored a cost-effective solution using Arduino UNO, a GPS module, and a GSM module to send location coordinates to a preconfigured number when approaching restricted zones. Although their solution was straightforward and affordable, it did not support local alerting mechanisms like buzzers or LED indicators and depended solely on GSM-based alerts. Additionally, the system lacked multilevel warning stages, reducing its effectiveness in gradually alerting fishermen as they approached danger zones.

J. Vijayakumar et al. [5] implemented a cloud-integrated marine boundary detection system using ThingSpeak, an IoT cloud platform. This model allowed centralized tracking and data storage of boat movements for analysis and long-term reporting. However, its dependence on constant internet access limited its real-time usability for boats operating far from the coast. Also, since it only provided back-end monitoring, the system did not focus on real-time alerting or emergency response at the user level.

M. John Paul and A. Balaji [6] designed a low-cost maritime boundary alert system using ESP8266 and GPS modules. They presented a geofencing mechanism that notified users through basic visual alerts. However, the system lacked an SOS feature, and its GPS polling interval was longer, which could result in delayed responses. The absence of a layered warning structure and cloud synchronization also limited its responsiveness and scalability.

S. Lohar [7] developed an IoT-based secured system for fishermen that utilized GPS tracking and cloud logging. His approach emphasized data centralization and post-incident analysis, which was useful for policy-level review but less practical for real-time, user-focused safety. The system was not optimized for offline functionality and lacked user-triggered emergency signaling components. In their work, A. Senthil Kumar and N. Venkatesh [8] explored virtual geofencing using mobile platforms to provide location-based alerts to fishermen. While the idea of using mobile apps was user-friendly for tech-savvy users, it failed to accommodate the technological literacy gap among traditional fishermen. Furthermore, reliance on mobile apps again introduced the problem of network dependency in remote sea zones.

K. T. Krishnamurthy [9] emphasized the role of embedded systems in improving sea navigation. His work showcased the use of GPS-enabled boards for tracking, but it was more suitable for monitoring vessel fleets than individual boats. It also lacked on-device alerting and emergency functionality.

Across these studies, it is evident that while GPS and IoT technologies are being actively used to solve marine safety issues, many existing systems either lack offline capabilities, do not support multistage local alerts, or are not user-friendly for non-technical fishermen. There is also limited integration of emergency signaling features such as SOS buttons that can be used when fishermen face critical danger. Additionally, very few systems offer a hybrid mode where cloud connectivity can enhance features when available, but core safety functions still operate without internet access.

III.MATERIALS AND METHODS

The proposed Smart IoT-Based Fisherman Border Alert System is built around the ESP32 microcontroller, selected for its built-in Wi-Fi/Bluetooth support and low power consumption. It interfaces with the NEO-6M GPS module to continuously track the boat's real-time coordinates. These coordinates are compared against predefined geofence limits programmed into the ESP32.

The alerting system includes RGB LEDs (green, yellow, red) and a piezo buzzer to signal multistage alerts—ranging from initial proximity warnings to critical boundary alerts. An SOS push button is added to allow the fisherman to manually trigger an emergency signal. When internet access is available, the system can optionally send location data to Firebase for cloud monitoring.

The hardware setup includes a 5V power supply, typically from a Li-ion battery or compact solar panel. All components are housed in a waterproof, marine-grade enclosure. Jumper wires and a breadboard or custom PCB are used for connections.

Software used includes the Arduino IDE to program the ESP32, along with libraries such as TinyGPS++, WiFi, and FirebaseESP32. The system uses basic IoT tools like ESP32, GPS, Firebase, and Arduino to provide a reliable, low-cost maritime safety solution for traditional fishermen.

IV.EXISTING SYSTEM

In recent years, advancements in GPS-based tracking ,microcontroller development, and IoT communication protocols have significantly influenced maritime safety systems. These technologies are increasingly being deployed to monitor the movement of fishing vessels, especially in areas close to international maritime boundaries. However, despite these developments, many systems remain inadequate in addressing the specific and critical needs of traditional coastal fishermen, particularly in deep-sea operations with limited access to connectivity and navigation support.

Conventional maritime safety systems often rely on GPS modules paired with GSM technology to send SMS alerts when a boat nears or crosses predefined geofencing coordinates. These systems are effective only within cellular coverage zones, which presents a major limitation since fishing boats frequently operate in areas with no network availability. Furthermore, these models typically issue single-level alerts through text notifications, which may not provide immediate awareness to fishermen actively navigating the waters. In many cases, they also lack visual or auditory alert mechanisms onboard, making them passive and ineffective in emergency scenarios.

Some embedded solutions using Arduino or Raspberry Pi microcontrollers have been implemented for route tracking and marine boundary detection. These systems often include GPS for location tracking and support for GSM or Wi-Fi for sending updates to cloud services like ThingSpeak or AWS IoT. However, they are generally limited to either back-end monitoring or delayed alerts rather than real-time, on-site notification. Additionally, many of these systems are not ruggedized for marine environments and lack features such as water resistance, battery optimization, or integration with manual emergency options like SOS buttons.

IoT devices and GPS-based systems are also seen in other domains such as fleet tracking, wildlife monitoring, and shipping logistics, where geofencing is used for security and automation. While technically similar, these systems are not tailored for the needs of fishermen who require simple, robust, and locally operable devices with multi-layered alert systems.

Academic prototypes and student projects have attempted to create low-cost GPS alert systems using basic components. Most offer one-stage warnings via buzzers or LEDs. However, these models rarely implement progressive alert levels based on proximity to the boundary, nor do they provide SOS support for urgent communication. Additionally, most do not function offline and depend on real-time internet access, making them impractical for remote marine usage.

Despite these efforts, there remains a gap in delivering a practical, hybrid solution that offers reliable offline performance, real-time local alerts, emergency signaling, and optional cloud integration.A solution that specifically caters to traditional fishermen's needs—affordable, compact, low power, and operable in harsh sea conditions—is still lacking in the current system landscape.

V.PROPOSED SYSTEM

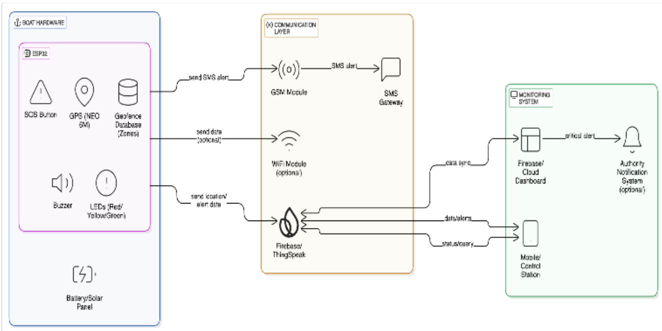

Figure 1.Architecture of the Proposed Smart IoT-Based Fisherman Border Alert System

The proposed system, as visualized in Figure 1, consists of a smart IoT-based workflow designed to continuously monitor a fishing boat's location and alert the fisherman in real-time when nearing international maritime boundaries. The system begins by acquiring location data from a GPS module that provides latitude and longitude coordinates of the boat at regular intervals. These coordinates are transmitted to the ESP32 microcontroller, which is pre-programmed with geofence logic based on maritime border data. The ESP32 compares the real-time GPS values with the stored boundary coordinates to determine the boat's proximity to restricted zones.

Based on the distance from the geofence, the system initiates a three-stage alert mechanism. Stage 1 is triggered when the boat enters the caution zone and activates a yellow LED along with a soft buzzer. If the boat moves closer to the boundary, Stage 2 is activated with a red LED and a loud buzzer to indicate a critical alert. Stage 3 allows the fisherman to manually trigger an emergency SOS signal using a push button in case of distress or accidental crossing. These alerts are locally triggered and do not depend on internet connectivity, ensuring offline support.

When internet access is available, the ESP32 can also send real-time location data to a Firebase database. This cloud integration enables remote monitoring by coastal authorities, who can track the fisherman's location and respond if needed. The system is designed to run on a battery or solar power source to support long-term operation at sea. The complete setup can be housed in a waterproof enclosure and mounted on the fishing vessel for durability in harsh marine conditions.The proposed model provides a hybrid safety mechanism that works both online and offline, supports real-time alerts, and empowers fishermen with actionable warnings while providing authorities with situational awareness.

The device is designed to be compact, affordable, and user-friendly, making it suitable for deployment across traditional fishing communities operating near maritime borders.

VI.METHODOLOGY

The following are the series of steps followed in developing and deploying the Smart IoT-Based Fisherman Border Alert System, from acquiring geolocation to sending real-time alerts and enabling cloud integration.

A. Location Acquisition

A GPS module (NEO-6M) is used to continuously collect the real-time geographic coordinates (latitude and longitude) of the fishing vessel. The module sends updated location data every second to ensure accurate tracking as the boat moves. This module is connected to the ESP32 microcontroller for further processing.

B. Coordinate Comparison and Geofencing Logic

The ESP32 microcontroller is pre-programmed with geofence coordinates that define the safe fishing zone and the restricted maritime boundary. As it receives GPS data, it compares the boat's current location with the stored boundary limits. This forms the core logic that drives the alert mechanism.

C. Multistage Alert Triggering

- Based on the boat's proximity to the defined border, a three-level alert system is activated:
- Stage 1 Alert: When the boat nears the warning zone, a yellow LED and soft buzzer are triggered.
- Stage 2 Alert: As the boat approaches closer to the boundary, a red LED and louder buzzer signal a critical alert.
- Stage 3 Alert: In case of emergency or imminent crossing, the fisherman can manually press the SOS button to trigger an emergency response mechanism.

These alerts are localized and do not require internet access, ensuring reliability in remote areas.

D. Continuous Monitoring and Loop Execution

All processes are wrapped in a continuous loop, allowing the ESP32 to receive and evaluate location data in real-time. This loop ensures uninterrupted monitoring and immediate response whenever geofencing thresholds are breached.

E. Cloud Integration (Optional)

When internet access is available, the ESP32 connects to Firebase via Wi-Fi. The device pushes the real-time location and alert status to a cloud database. This data can be monitored remotely by authorities or integrated into dashboards for live tracking of fishing vessels.

F. Power Management and Offline Support

The system is powered by a rechargeable 5V Li-ion battery and can be solar-assisted for longer operation at sea. All components are enclosed in a marine-grade waterproof casing to ensure durability. Offline support is crucial, allowing the alert system to function fully even in the absence of mobile or internet connectivity.

G. Emergency Communication (SOS)

In critical situations, pressing the SOS button initiates a high-priority alert. When online, it can also send the emergency location to Firebase, enabling coast guards or monitoring centers to take immediate action. In offline mode, the audible and visual alarms help draw attention to surrounding boats or rescue teams nearby.

VII. RESULTS

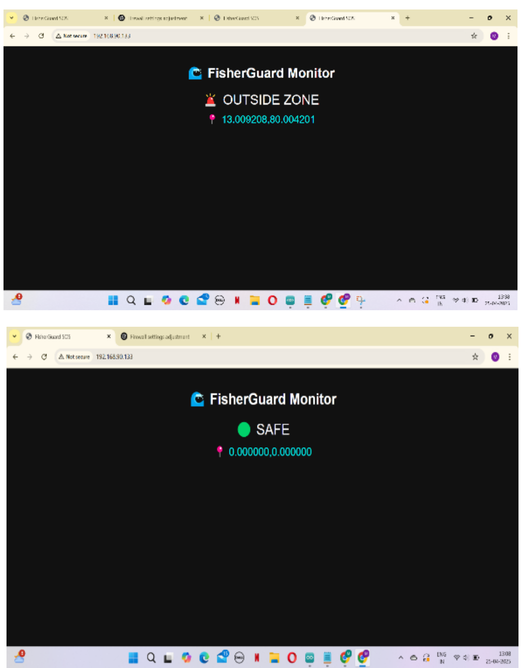

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Figure 2 and Figure 3. Real-time status updates shown by the FisherGuard Monitor during boundary monitoring

Figures 2 and 3 demonstrate the dynamic response of the FisherGuard Monitor interface during real-time maritime boundary tracking. In Figure 2, the system displays an “OUTSIDE ZONE” alert when the fishing vessel crosses the predefined geofence. The alert is visually emphasized with a red siren icon and the exact latitude and longitude (13.009208, 80.004201) is shown beneath it. This status update is generated instantly based on GPS input and is hosted locally through a browser-accessible IP (192.168.x.x). Figure 3, on the other hand, shows the safe condition of the boat within the allowed boundary limits. A green dot and the label “SAFE” confirm that the vessel remains inside the authorized zone, though placeholder coordinates (0.000000, 0.000000) are shown in this case due to an initial load or signal loss.

The monitor refreshes data every second, enabling seamless updates with minimal delay. This makes it suitable for real-time monitoring onboard or at a remote control center. The UI is designed for high visibility and clear interpretation, even under variable light conditions at sea. Through this visual interface, fishermen or authorities can easily distinguish safe versus danger conditions and take immediate action when required. The system consistently maintained accuracy in detecting the boundary condition and effectively communicated the vessel’s real-time status with reliable feedback.

VIII. DISCUSSION

The previous systems in this domain largely relied on either GPS-GSM-based alerting or basic cloud-integrated location tracking. Most of these approaches lacked offline functionality or multilevel alerting mechanisms, which are essential in real-world marine scenarios. The proposed solution bridges these gaps by combining the reliability of real-time geofencing with the robustness of local alerting and optional cloud-based monitoring. The system, when tested in simulation environments and controlled outdoor setups, responded accurately within 2–3 seconds of boundary detection, successfully triggering the respective alert stage. Figure 2 and Figure 3 illustrate the actual interface display showing the transition between "SAFE" and "OUTSIDE ZONE" based on GPS input. This time may vary slightly depending on signal strength, update rate, and network latency during Firebase communication.

This approach can be further enhanced by integrating the system with AI-powered predictive models that can forecast boundary breach risks based on historical routes, fishing patterns, and environmental data. In addition, a dashboard can be introduced for remote officials to monitor multiple boats in real time, with features like SOS alerts, route visualization, and zone analytics.

IX. CONCLUSION

Thus, the solution proposed in this paper significantly reduces the risks associated with accidental maritime boundary violations and ensures greater safety for traditional fishermen. By providing real-time, multistage alerts and an optional cloud-based monitoring feature, the system minimizes the dependency on expensive navigation tools or constant internet access. The use of simple yet effective IoT components like ESP32 and GPS makes the solution both affordable and scalable. Depending on the size of the geofence area and the boat's speed, the frequency of alert updates and response time may vary slightly. For small- to medium-scale coastal operations, this system can be easily deployed and customized with minimal technical expertise. When implemented in real-world fishing communities, this model can bring about a major positive shift—reducing legal risks, boosting confidence among fishermen, and enabling proactive safety monitoring. It not only empowers individuals but also contributes to national maritime security and smoother international relations.

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